Chapter (1)

Physics of MOSFET Transistor

Problems

((اللهمَّ رحمتكَ أرجو ، فلا تكِلْني إلى نفسي طرْفَةَ عيْنٍ ، وأصلحْ لي شأنيَ كلَّه ، لا إله إلا أنتَ))

Problems

In the following problems, unless otherwise stated, assume $\mu_n C_{ox} = 200\ \mu A / V^2$, $\mu_p C_{ox} = 100\ \mu A / V^2$, and $V_{TH} = 0.4\ V$ for NMOS devices and $-0.4\ V$ for PMOS devices.

1. Calculate the total charge stored in the channel of an NMOS device if $C_{ox} = 10\ fF / \mu m^2$, $W = 5\ \mu m$, $L = 0.1\ \mu m$, and $V_{GS} - V_{TH} = 1\ V$. Assume $V_{DS} = 0$.

2. An NMOS device carries 1 mA with $V_{GS} - V_{TH} = 0.6 V$ and 1.6 mA with $V_{GS} - V_{TH} = 0.8\ V$. If the device operates in the triode region, calculate V_{DS} and W / L.

3. An NMOS device operating with a small drain-source voltage serves as a resistor. If the supply voltage is 1.8 V, what is the minimum on-resistance that can be achieved with $W / L = 20$?

4. We wish to use an NMOS transistor as a variable resistor with $R_{on} = 500\ \Omega$ at $V_{GS} = 1\ V$ and $R_{on} = 400\ \Omega$ at $V_{GS} = 1.5\ V$. Explain why this is not possible.

5. In the circuit in Fig.1, shown, M_1 serves as an electronic switch. If $V_{in} \sim 0$, determine W / L such that the circuit attenuates the signal by only 5%. Assume $V_G = 1.8\ V$ and $R_L = 100\ \Omega$.

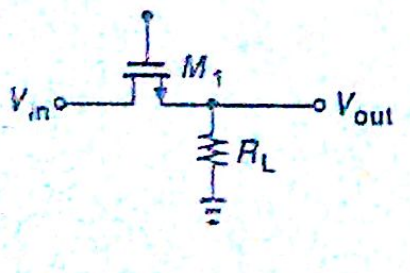
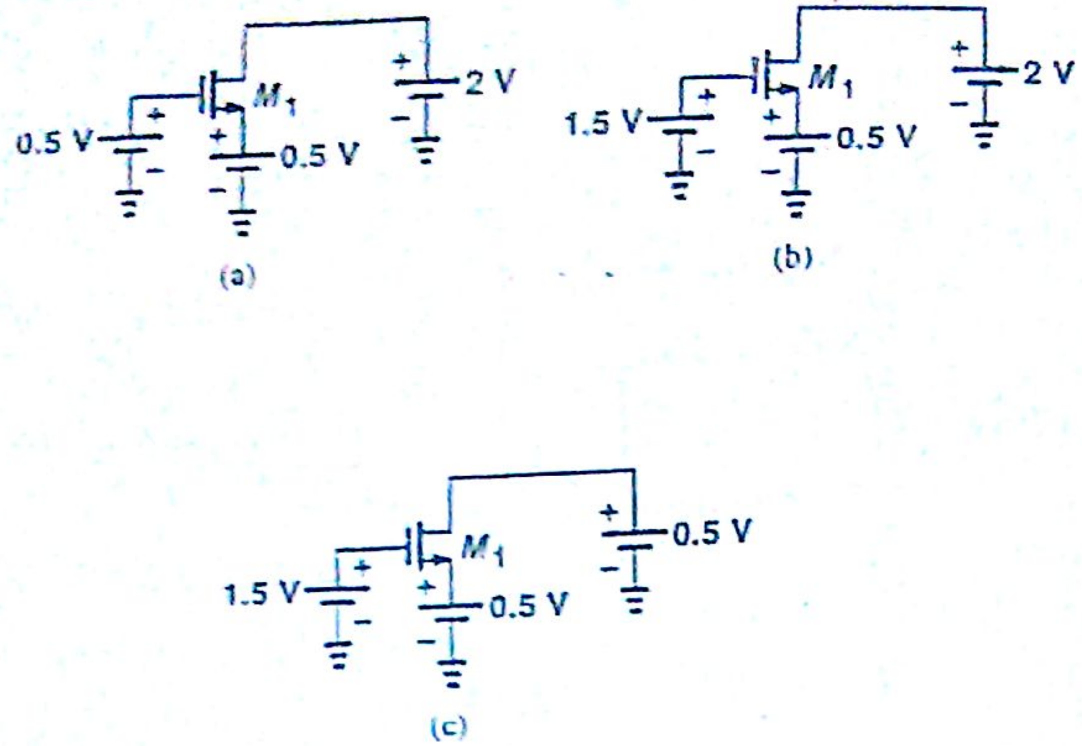


Fig.1

6. Determine the region of operation of M_1 in each of the circuit shown in Fig.2

Fig.2



7. Determine the region of operation of M_1 in each of the circuit shown in Fig.3

Fig.3

(1) Total charge stored in channel = ? (1)

$C_{ox} = 10\ fF/\mu m^2$, $W = 5\mu m$, $L = 0.1\mu m$

$V_{GS} - V_{TH} = 1V$. assume $V_{DS} = 0$.

Solution:-

$Q(x) = W C_{ox}[V_{GS} - V(x) - V_{TH}]$

$\because V_{DS} = 0$

$\therefore V(x) = 0$.

$\therefore Q(x) = W C_{ox}[V_{GS} - V_{TH}]$.

$\therefore Q(x) = 5 \times 10^{-6} \times 10 \times 10^{-15} \times 10^{+12} [1]$

$\therefore Q(x) = 5 \times 10^{-8}\ c/m$.

$\Downarrow$

channel charge density $= \dfrac{\text{charge}}{\text{length}}$.

$\therefore$ Total charge $= Q(x) \times L$

$\therefore$ Total charge $= 5 \times 10^{-8} \times 0.1 \times 10^{-6}$

$= 5 \times 10^{-15}$ electrons

(2) $I_D = 1mA \longrightarrow (V_{GS} - V_{TH}) = 0.6V$

$I_D = 1.6mA \longrightarrow (V_{GS} - V_{TH}) = 0.8V$

if MOSFET in Triode region

Calculate V_{DS} and W/L.

Solution:

∴ in Triode regions.

$$I_D = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}\left[2(V_{GS}-V_{TH})V_{DS} - V_{DS}^2\right].$$

$$\therefore 1mA = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}\left[2 \times 0.6 \times V_{DS} - V_{DS}^2\right] \longrightarrow (1)$$

$$1.6mA = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}\left[2 \times 0.8 \times V_{DS} - V_{DS}^2\right] \longrightarrow (2)$$

بقسمة (1) على (2)

$$\therefore \frac{1}{1.6} = \frac{1.2V_{DS} - V_{DS}^2}{1.6V_{DS} - V_{DS}^2}$$

$$0.6V_{DS}^2 - 0.32V_{DS} = 0.$$

$$\therefore V_{DS}\left[0.6V_{DS} - 0.32\right] = 0.$$

$$\therefore V_{DS} = 0 \qquad V_{DS} = \frac{0.32}{0.6} = 0.533$$

$V_{DS} = 0 \longrightarrow$ مرفوض

$\therefore V_{DS} = 0.533\ V$

بالتعويض في المعادلة (1)

$$\therefore 1mA = \frac{1}{2} \times 200 \times 10^{-6} \times \frac{W}{L}\left[2 \times 0.6 \times 0.533 - 0.533^2\right]$$

$$\therefore W/L = 28.1$$

(3) NMOSFET $\longrightarrow$ resistor.

Supply voltage $= 1.8\ V$

What is the minimum on-resistor $= ?$

$W/L = 20$

Solution:-

$$R_{on}\downarrow = \frac{1}{\mu_n C_{ox} \frac{W}{L} (V_{GS} - V_{TH})}$$

$\therefore R_{on}\downarrow \quad V_{GS}\uparrow = 1.8\ V.$

$$\therefore R_{on} = \frac{1}{200 \times 10^{-6} \times 20 \times (1.8 - 0.4)}$$

$$= 178.57\ \Omega.$$

(4) N MOSFET

$R_{on} = 500\,\Omega \longrightarrow V_{GS} = 1\,V$

$R_{on} = 400\,\Omega \longrightarrow V_{GS} = 1.5\,V$

Explain why this is not Possible.

Solution:

$$\therefore R_{on} = \frac{1}{\mu_n C_{ox} \frac{W}{L} (V_{GS} - V_{TH})}$$

$$\therefore W/L = \frac{1}{\mu_n C_{ox} R_{on} (V_{GS} - V_{TH})}$$

When $R_{on} = 500\,\Omega$

$$\therefore W/L = \frac{1}{200 \times 10^{-6} \times 500 \times (1 - 0.4)}$$

$$\therefore W/L = 16.7 \longrightarrow (1)$$

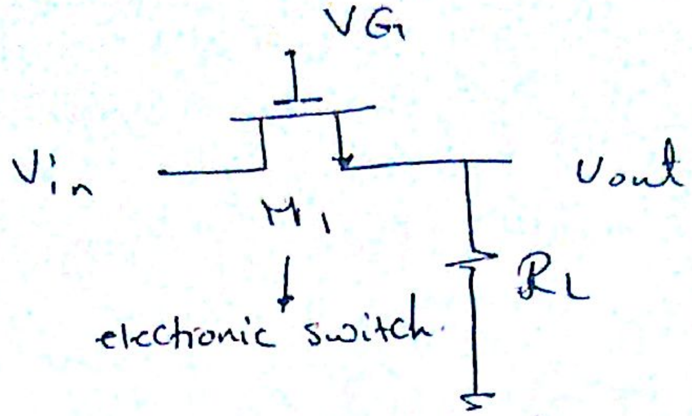
When $R_{on} = 400\,\Omega$

$$\therefore W/L = \frac{1}{200 \times 10^{-6} \times 400 (1.5 - 0.4)}$$

$$\therefore W/L = 11.36 \longrightarrow (2)$$

⑤ من (1) ، (2) نلاحظ إضرب في W/L ، هنستعمل .

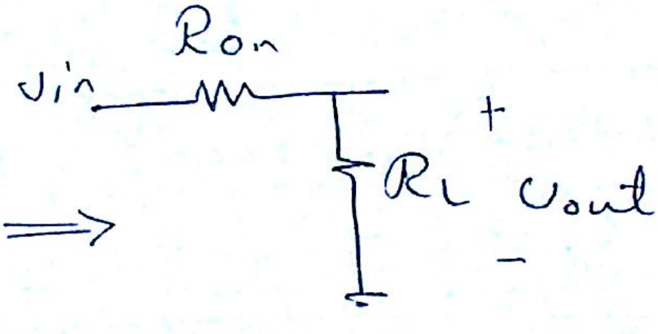
(5)



determine W/L = ? . the circuit attenuates the signal by only 5 % , VG = 1.8 V , RL = 100 Ω.

Solution

$V_{in} = V_{in} \Longrightarrow$



$= 95\% V_{in}$

$\therefore V_{out} = 0.95\ V_{in}$.

$\therefore \frac{V_{out}}{V_{in}} = 0.95 \longrightarrow (1)$

$\therefore V_{out} = V_{in} * \frac{R_L}{R_L + R_{on}}$

$\therefore \frac{V_{out}}{V_{in}} = \frac{R_L}{R_L + R_{on}} \longrightarrow (2)$

(6)

from (1) & (2)

$$\therefore \frac{R_L}{R_L + R_{on}} = 0.95$$

$$\therefore R_L = 0.95 R_L + 0.95 R_{on}$$

$$\therefore R_{on} = \frac{0.05 R_L}{0.95} = \frac{0.05 \times 100}{0.95} = 5.26\,\Omega$$

$$\because R_{on} = \frac{1}{\mu_n C_{ox} \frac{W}{L} (V_{GS} - V_{TH})}$$

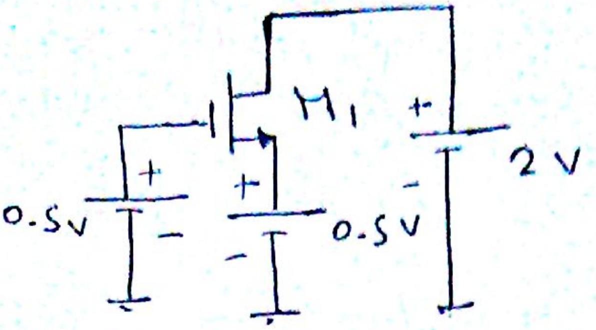
$$\therefore W/L = \frac{1}{\mu_n C_{ox} R_{on} (V_{GS} - V_{TH})}$$

$$\therefore W/L = \frac{1}{200 \times 10^{-6} \times 5.26 (1.8 - 0.4)}$$

$$\therefore W/L = 678.9$$

Determine the region of operation ? (7)

(a)

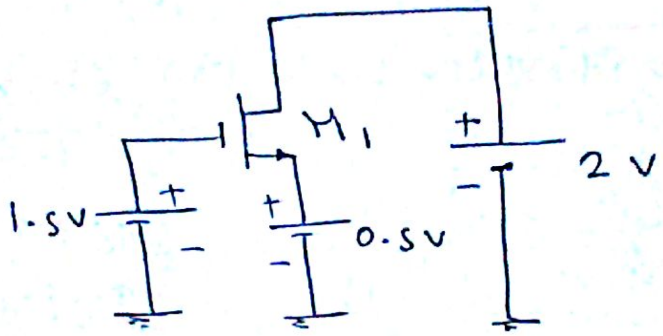


$V_{GS} = 0 < V_{TH}\ (0.4V)$ ∴ No channel

∴ $I_D = 0$

∴ $M_1 \longrightarrow$ Cutoff region.

(b)



$V_{GS} = V_G - V_S = 1.5 - 0.5 = 1V > V_{TH}.$

وممكن هنا باستخدام V_{DS}.

$V_{DS} = 2 - 0.5 = 1.5\ V$

$V_{GS} - V_{TH} = 1 - .4 = 0.6\ V$

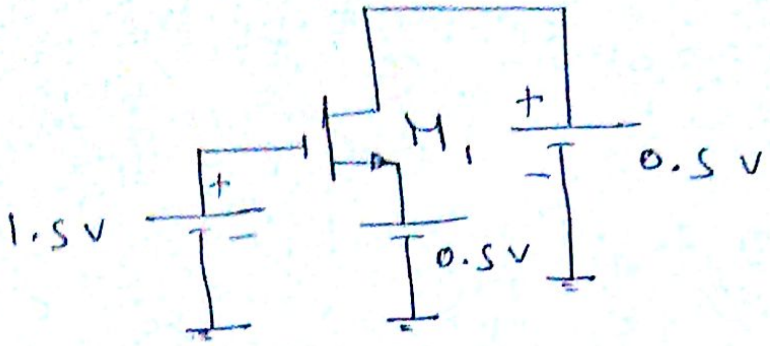
∴ $V_{DS} > V_{GS} - V_{TH}$

∴ $M_1 \rightarrow$ saturation

$\boxed{V_{GD} = V_G - V_D = 1.5 - 2 = -0.5\ V \qquad V_{GD} < V_{TH}\ (0.4V)}$

∴ $M_1 \longrightarrow$ Saturation region

(c)



$V_{DS} = 0V$

$\therefore I_{SD} = 0$

$\therefore M_1 \rightarrow$ Cut off

$$V_{GS} = 1.5 - 0.5 = 1V > \overset{0.4V}{V_{TH}}.$$

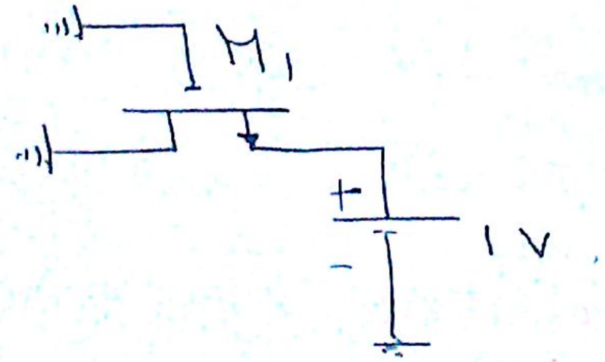
$$V_{GD} = V_G - V_D = 1.5 - 0.5 = 1V > \overset{0.4V}{V_{TH}}$$

but $V_{DS} = 0$ $\therefore I_D = 0$

$\therefore M_1 \longrightarrow$ Cut off region

(7) Determine the region of operation ?

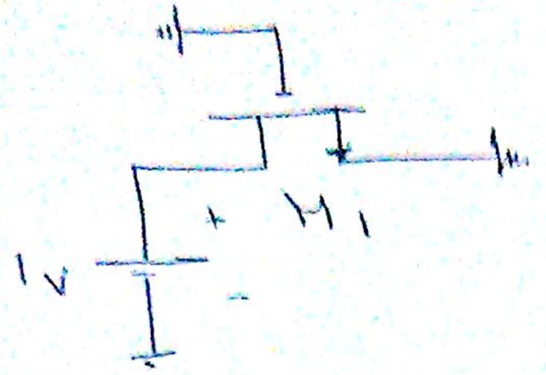
(a)



$$V_{GS} = V_G - V_S = 0 - 1 = -1 < \overset{0.4V}{V_{TH}}$$

$\therefore M_1 \longrightarrow$ Cut off

(b)



$0.4\,V$

$V_{GS} = V_G - V_S = 0 - 0 = 0 < V_{TH}$

$\therefore M_1 \longrightarrow$ Cutoff.

إهام

(8) it is Possible to defined an "intrinsic Time Constant" for a MOSFET operating an resistor $\tau = R_{on} C_{GS}$

Where $C_{GS} = W L C_{ox}$

obtain an expression for τ and explain what is the circuit designer must do to minimize the Time Constant

Solution

$\therefore \tau = R_{on} C_{GS}$

$$R_{on} = \frac{1}{\mu_n C_{ox} \frac{W}{L} (V_{GS} - V_{TH})}$$

$\because C_{GS} = WLC_{ox}$.

$\therefore \tau = \frac{1}{\mu_n \cancel{C_{ox}} \frac{W}{L} (V_{GS} - V_{TH})} \times \cancel{W} L \cancel{C_{ox}}$

$\therefore \tau = \frac{L^2}{\mu_n (V_{GS} - V_{TH})}$

To minimized the time constant.

* use minimum L

* Maximized overdrive voltage

$\downarrow$

$(V_{GS} - V_{TH})$

Good Luck